ERDC TN-DOER-C13
July 2000

Determining Recovery Potential of Dredged Material for Beneficial Use – Soil Separation Concepts

PURPOSE: This is the first of three technical notes providing guidance in evaluating dredged material recovery potential. This technical note provides an overview of physical separation (soil washing) concepts, and methods for calculating volumes of recoverable material meeting beneficial use (BU) requirements. The other technical notes address data acquisition for volume estimation. The second (Olin-Estes and Palermo 2000) outlines a prescriptive approach, using existing information obtained from limited sampling, to estimate volumes meeting BU requirements. The third (Olin-Estes 2000) introduces statistical methods for developing a more extensive sampling plan, and methods of organizing and interpreting data.

BACKGROUND: Contaminated dredged material is often placed in confined disposal facilities (CDFs), but as land development and acquisition costs continue to rise, there is a growing shortage of CDF storage capacity. Several options can be considered to increase capacity, including restricted disposal (that is, storage of only the most contaminated sediments), dredged material dewatering and densification, and, more recently, reclamation and reuse of materials from the CDF. Physical separation (soil washing) is a management approach that has been applied at several projects and holds promise as a potentially low-cost method to recover materials for BU and to restore CDF capacity.

Physical separation or soil washing in this context refers to the process of classifying or separating sediment into fractions according to particle size or density. Separation may be accomplished by screening, gravity settling, flotation, or hydraulic classification using devices such as hydrocyclones (Averett et al. 1990; Allen 1994; U.S. Environmental Protection Agency (USEPA) 1994b; Olin et al. 1999). Equipment for physical separation is widely available, and the concept has been demonstrated for sediments in both the United States and Europe (USEPA 1994a; Zwakhals, Deibel, and van Rijt 1995; Detzner, Kitschen, and Weimerskirch 1995; Granat 1998). Additionally, various site design and operational approaches can be effective in achieving separation during placement of dredged material in a conventional CDF (Olin and Bowman 1996; Zwakhals, Deibel, and van Rijt 1995). However, methods to evaluate the feasibility of separation for a given dredged material or for a given CDF site, considering environmental, logistical, and economic factors, are not yet well established (Olin and Bowman 1996).

The feasibility of separation as a management approach is dependent on several factors, including the ability to identify distinct fractions within the material meeting BU criteria, the ability to separate suitable fractions, and the material recovery potential (MRP) as determined by available volumes of suitable material. This technical note introduces the technical considerations of physical separation as applied to dredged material and provides a framework for evaluation of physical separation. Olin-Estes (2000) and Olin-Estes and Palermo (2000) address data acquisition and utilization for evaluating MRP. The information contained in those technical notes is applicable to MRP determination, not only for physical separation feasibility evaluation, but for BU recovery in general.

INTRODUCTION: An overall approach to evaluate feasibility of separation as a management option is illustrated in the flowchart in Figure 1. The need for recovery or preservation of CDF capacity should first be evaluated based on available capacity and projected future needs, although adequate long-term capacity need not rule out BU of dredged material. A screening examination of proposed BU applications for the locale should be conducted to determine if the material can be used without pretreatment. If available information is inadequate, at least limited sampling of the material will be needed to make a preliminary determination. Preliminary sampling and data acquisition are further discussed in Olin-Estes and Palermo (2000). If separation appears to be necessary to meet material specifications for identified BU, an evaluation of MRP and a more detailed sediment/site characterization and evaluation are needed. Extensive site sampling and data interpretation are further discussed in Olin-Estes (2000). Material characterization, physical separation processes and limitations, and determination of MRP are discussed in the following sections.

MATERIAL CHARACTERIZATION: Material characterization is necessary both to determine as-is suitability of material for BU and, when the material is found not suitable, to determine feasibility of physical separation for recovering usable fractions. Preliminary material characterization for BU screening generally includes a particle size distribution analysis and bulk (unseparated) chemical contaminant analysis, since acceptable grain size and contaminant levels are specified for most, if not all, BU. Other parameters may also be of interest, depending upon the BU specifications, but might include clay content, liquid limit, plastic limit, and moisture content.

If bulk material is found to be unsuitable as is for identified BU, a more comprehensive characterization is required. This typically implies a contaminant distribution, or fractionation, analysis in which material is separated into different size and density fractions. Fractionation studies permit evaluation of the quality of the respective size and density fractions of the material under consideration. Anecdotal evidence suggests that separation of sandy materials results in a large proportion of contaminants of concern (COC) remaining associated with the fine silt and clay fraction (Olin and Bowman 1996; Allen 1994; Olin et al. 1999). Although coarse minerals, sand size and larger, are typically relatively uncontaminated, in some cases efficient separation of coarse and fine fractions may be difficult. A clean coarse product will therefore be difficult to produce, or may require additional processing operations.

Organic materials of all sizes will typically have higher contaminant levels than any of the mineral fractions, including the clays, particularly for hydrophobic organic contaminants. The contribution of organic material to overall contaminant levels can be determined from a density fractionation study. Collectively, contaminant distribution information is used to determine whether or not an acceptable size or density fraction is likely to be recoverable from the material, what percentage of the material this represents, and what unit operations are likely to be needed to achieve this separation. Organically bound contaminants may be less available than mineralogically bound contaminants. Bioavailability may ultimately determine whether this fraction must be removed to produce a material suitable for beneficial use; this is typically a regulatory decision.

All samples should be physically tested prior to any chemical fractionation testing, since the physical tests are fast and inexpensive, will yield data that may rule out separation as a viable approach, and will indicate which samples should undergo chemical analysis. Chemical fractionation testing

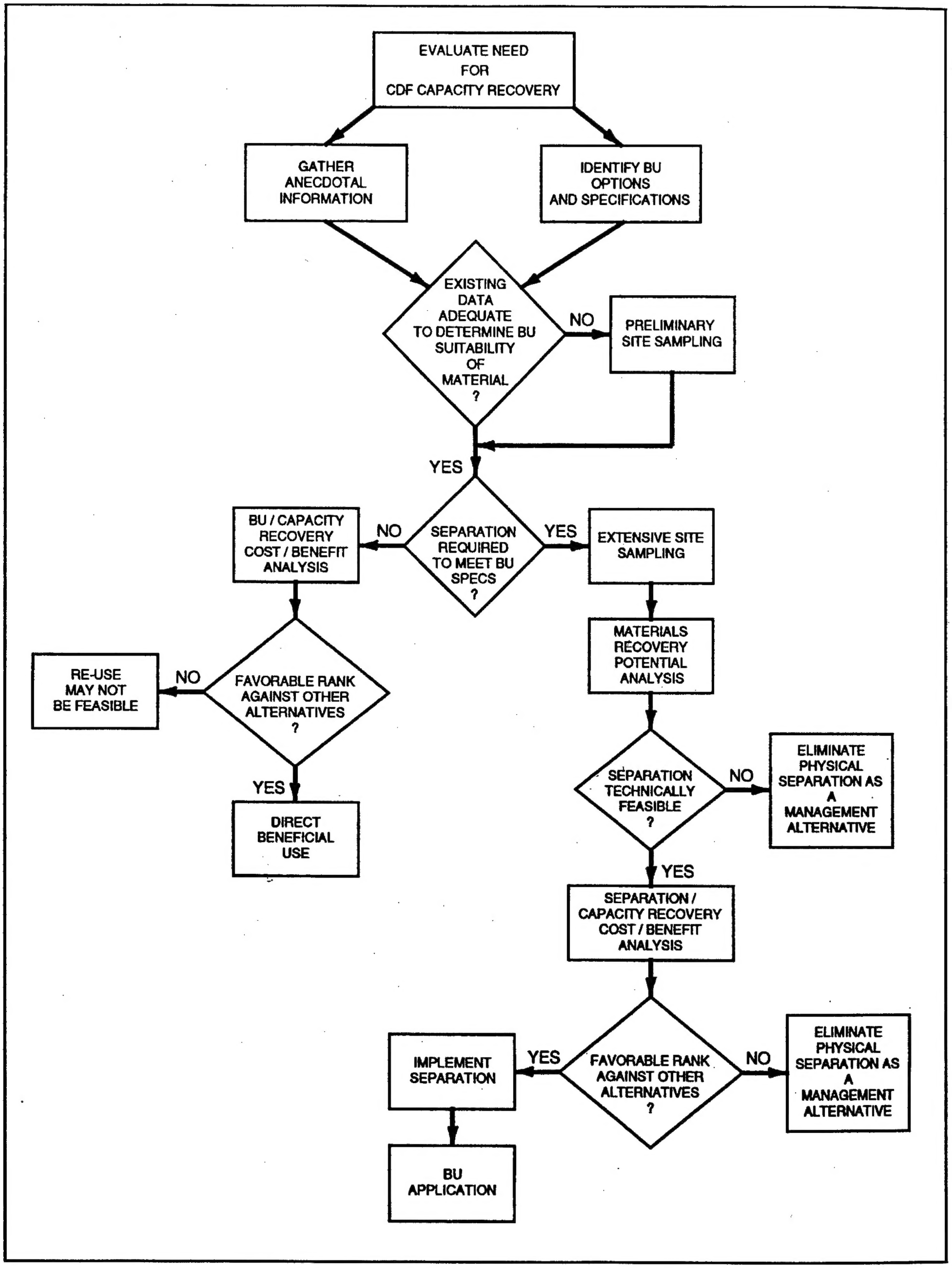


Figure 1. Evaluation of feasibility for BU recovery of dredged material

should be conducted only if the physical data indicate feasibility. The physical data may also lead to strategies for compositing samples for the contaminant distribution (fractionation) testing.

Selection of analytes for chemical analysis is a key component of the feasibility evaluation, and will significantly impact the overall cost of the site characterization. Ultimately, this is a regulatory issue. For preliminary site characterization, some cost savings can be achieved by limiting the number of analytes where possible. This may be done by doing a full suite of metals and organic compounds on a few bulk samples likely to represent the worst-case contamination. Compounds not detected in the bulk analysis can be eliminated from most of the fractionation testing, although a full suite should be done on all fractions of some samples. A 250-ml (8-oz) sample of dry or high-solids sediment is sufficient to conduct the following analyses, including standard quality assurance/quality control (QA/QC): Michigan Metals (arsenic, barium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc), and organic compound groups including base neutral/acid extractable (semivolatiles, BNA), polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and total recoverable petroleum hydrocarbons (TRPH). Additional material is required initially to produce this volume in each resulting fraction. Necessary starting sample volumes can be estimated from the bulk grain size distribution. If the volume of any fraction obtained following separation is insufficient, fractions may have to be composited, or limited analysis conducted, to obtain as much information as possible from those samples. Multiple samples may be composited only if this is representative of the manner in which the material will be blended for processing.

Existing characterization methods include the Fingerprint method and the TDG method. The Fingerprint method was developed by Heidemij Realisatie, now ARCADIS Realisatie (Olin et al. 1999), and is a pilot scale operation using hydrocyclones to produce six size fractions, followed by gravity separation of the density fractions. The TDG method is a bench scale characterization procedure developed by ARCADIS Realisatie and TNO Institute of Environmental and Energy Technology (Olin et al. 1999), producing three size fractions and three density subfractions. Test development for contaminant distribution determinations is an ongoing research effort under the Dredging Operations and Environmental Research (DOER) Program. Efforts are being directed to streamline and standardize the process and minimize costs, employing mineralogically significant size cut points (silt/sand and clay/silt) and an innovative density separation process. The procedures under development use equipment that is widely available (Olin et al. 1999). Contaminant distribution studies examining relative contaminant distribution behavior and the contribution of the clay fraction to overall contaminant levels are being conducted in connection with this effort. Guidance on this work will be provided in a subsequent DOER technical note.

PHYSICAL SEPARATION PROCESSES: The information quoted or summarized in this section was taken from Olin et al. (1999), to which the reader is referred for a more in-depth discussion of physical separation processes and equipment. "Much of the philosophy of volume reduction comes from hundreds of years of mining experience worldwide...The remediation engineer has the same challenge; to remove small amounts of contaminants from complicated and diverse feeds. Volume reduction uses a fundamental understanding of the physical and chemical characteristics of the feed soil or sediment and a simple, inexpensive treatment train to remove clean material. This results in a smaller mass of contaminated material to be either further treated or disposed." The focus here is on physical separation, but physical separation processes can be, and

often are, coupled with chemical treatment and extraction processes. The principal properties used in separation of sediment fractions are particle size and density. Surface chemistry and magnetic properties may play a role in isolated cases, but the majority of separations are made on the basis of size and density. Additionally, with the exception of screening processes, most separations are not purely size or density separations. While one parameter may predominate, some density effects will be felt in a size separator, and vice versa. There are five principal components of physical separation treatment trains: prescreening, primary physical size separation, density separation, solid/liquid separation, and dewatering.

"Prescreening refers to the removal, or reduction in size, of oversize materials from the bulk sediment that would interfere with downstream processing operations. Oversize materials are roughly 50 mm in size or larger." Oversized dredged material may consist of stones, tree limbs, and soil clumps, but may also include such unwieldy objects as cable, refrigerators, tires, or car bodies. As a result, the prescreening component may present some difficult challenges for dredged material processing operations. "Prescreening equipment may involve one or more of the following: feed hoppers, fixed bar screens (grizzlies), rotating trommel screens, comminutors, attritioners, log washers and hand picking."

Size separation is the central unit operation of the physical separation treatment train. "Because many contaminants associate chiefly with the finer soil fractions, separation of sand size particles (>75 μm) from silts and clays (<75 μm) is typically the foundation on which the remainder of the soil washing treatment train is established and refined. Size separation equipment may include one or more of the following processes: screens (fixed or vibrating, wet or dry), hydrocyclones and sieve bends."

Density separation is useful when there are significant amounts of either low-density organic material or high-density metal fragments. Most mineral components of sediments do not differ enough for density separations to be valuable, but sediments and dredged material may well contain various amounts of organic material that can be successfully separated from the mineral fraction. Because anthropogenic contaminants have a high affinity for organic material, removal of organic material may be necessary to produce a clean fraction, even within the coarsest materials. "A density separation circuit might include: spiral concentrators, mineral jigs, multi-gravity separators, dense media, shaking tables or a pinched sluice. Spiral concentrators and jigs are most commonly utilized in remediation."

With the possible exception of prescreening for oversized material, physical separation processes require that the material be slurried with water for processing. The high volume of water introduced is one of the chief disadvantages of physical separation as a management strategy. "Gross separation of the solids and water is achieved with solid/liquid separation processes, typically utilizing clarifiers, sedimentation basins, lamella clarifiers or flotation cells."

Dewatering is essentially a second-stage solid/liquid separation process, necessary to produce a material dry enough to handle. "Solids concentrations of 45% to 80% are possible, depending upon the size of the material and the dewatering processes used. Fine materials are the most difficult to dewater and typically represent a significant portion of overall processing costs. A dewatering

circuit might utilize one or more of the following: screens, belt filter presses, plate and frame filter presses, centrifuges, screw classifiers or rotary vacuum filters."

More detailed descriptions of this equipment are available in Olin et al. (1999), and include feed requirements, capacity, and, where available, general capital and operating cost ranges. Sample treatment trains and case studies are described in Olin et al. (1999) also.

DETERMINATION OF MRP

Data Requirements. Several types of data are required to estimate MRP:

- Bulk sediment data:
  Volume of available bulk sediment or dredged material.
  Grain size distribution (GSD) of the bulk material (prior to separation).
  Concentrations of COC in the bulk sediments.
- BU specifications, including acceptable GSD; COC levels; and quantity, seasonal, and logistical requirements.
- Concentrations of COC in material fractions, if separation is determined to be necessary to meet BU specifications.

Information Sources. Project surveys and data from prior testing are the most likely sources of existing information. Although materials to be dredged or previously disposed in a CDF are typically characterized to some degree, both physically and chemically, this information was likely not obtained or structured with an eye toward evaluation of MRP and separation feasibility. Even so, percent sand and bulk contaminant levels are usually known, and can be useful for initial screening and MRP estimates, if the coarse material is assumed to be relatively clean. More targeted sampling and analysis will likely be required to obtain definitive information.

While project data related to sediment physical and chemical characteristics as described previously are usually available for a number of stations in the case of in-channel evaluations, spatial data are rarely available for in-CDF materials. Some idea of material properties in the CDF must be inferred from existing in-channel data, CDF site surveys and visual inspections of the CDF surface, and knowledge of CDF filling operations. In both in-channel and in-CDF locations, additional data should be obtained through sampling and testing if the initial screening evaluations indicate separation may be necessary and feasible. Olin-Estes and Palermo (2000) and Olin-Estes (2000) contain further guidance on prescriptive and statistical sampling approaches, respectively.

Volume Estimates. The volumes of material available, either in-channel or in-CDF, will be defined by survey information. Volumes available, either on a periodic basis or on a one-time basis, must be comparable to those required for the BU application and must be large enough to achieve economies of scale. Also, the effect of bulking and of concentration of COCs in the separated fine fraction must be evaluated in determining CDF capacity ultimately recoverable.

Material Specifications. The principal material specifications are typically related to grain size and contaminant level. The specifications for acceptable grain size for a given BU application will

depend on the intended application. From the physical standpoint, the material specifications may be an average grain size (D_{50}) or a target GSD. The specifications may also include an acceptable percentage of material finer or coarser than the desired range. For example, Figure 2 illustrates the desired grain size range for a BU application for beach nourishment (note that specifications will be site specific).

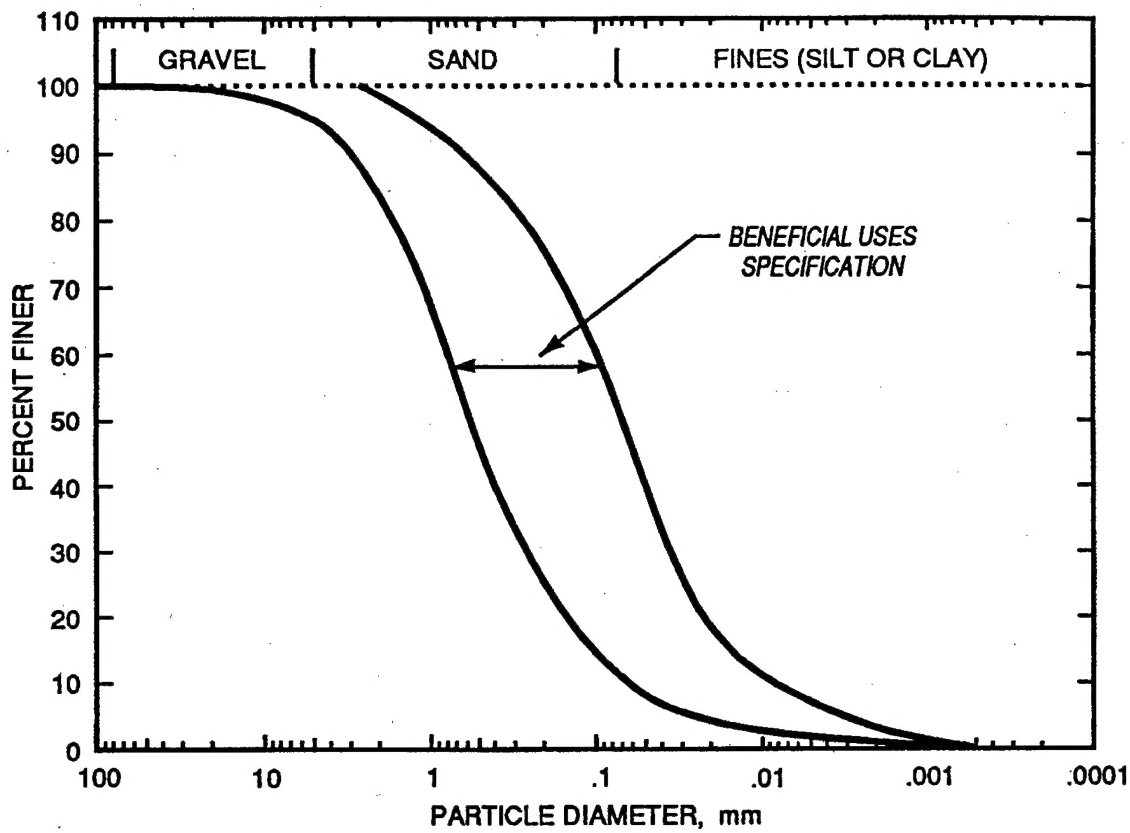


Figure 2. BU grain size specification example

Acceptable levels of COC are usually a function of environmental regulations or guidelines pertaining to the type of activity associated with the BU application. Normally, these criteria or standards will include specific concentrations of contaminants allowable, on a dry weight basis, in a material intended for a specific BU. Regulatory agencies in some states have proposed or adopted policies encouraging reuse of materials and provide for a case-by-case review and determination of requirements (Olin 1998).

As previously discussed under "Material Characterization," the material specifications for anticipated BU should first be compared to the bulk material properties (as they exist prior to any separation) to determine if the material can be used beneficially as is. Because chemical analysis is extremely expensive, physical parameters, which can be quickly and inexpensively determined, should be evaluated first. Grain size distribution may rule out certain BU without any further analysis, or help to target a limited number of samples for chemical analysis if the GSD is compatible

with the proposed BU. Depending upon the variability of the site, the GSD may be an average for the whole site or a section or sections of the site under consideration. If the GSD is acceptable, it should then be determined if the COC in the bulk material are at levels below all limiting concentrations for the BU application. If all COC are at concentrations below the BU requirements and the material GSD falls within the BU specifications for the entire site or portion under consideration, no separation is needed and the material can be applied to the BU as is. This is illustrated in Figure 3. The MRP evaluation in this case is simply to determine if the volumes available on a one-time or recurring basis will meet the needs for the BU application under consideration.

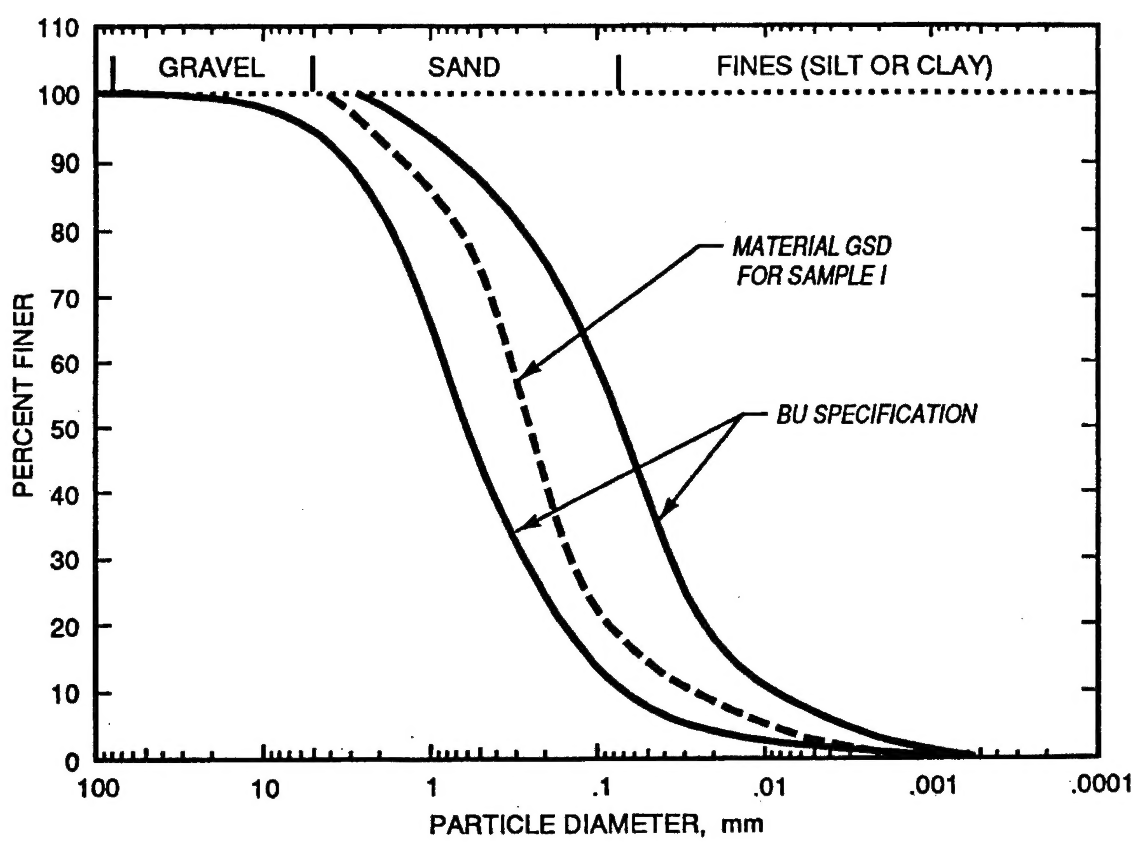


Figure 3. GSD falling within BU specification

If the bulk material does not meet requirements as is, the potential for separation to meet the requirements must first be assessed in general terms. A number of factors should be considered: preliminary targeted size or density cut, the technical difficulty of making the targeted separation, potential for regulatory classification changes in concentrated residual materials. The simplest separation from a technical perspective is a sand/silt separation. A silt/clay separation is technically more difficult, but may be worth considering if removal of the clay would permit recovery and reuse of the silt fraction as well. Acceptable COC levels in residual materials would be tied to any threshold that may require an increased level of treatment or management compared to the preseparation condition, e.g., the 50-ppm threshold for PCB triggering management under the Toxic

Substances Control Act (TSCA). Cost to manage such materials must be considered in the economic analysis if the potential to produce them exists. Preliminary chemical characterization will be important in this regard.

Screening criteria can be applied for the entire sediment mass within a waterway or to specific reaches within the waterway if such reaches define areas with similar characteristics, or if the reaches will be separately handled. Similarly, the screening criteria can be applied to the entire dredged material mass within the CDF for proposed reclamation or to separate zones, such as areas with materials having higher coarse fractions (such as mounds near inflow points). Compositing of samples during characterization should be done carefully, however. If separation is planned, samples should not be composited unless materials will be blended in a similar manner for processing (Olin et al. 1999).

Calculation of MRP. The calculation of MRP is derived from a comparison of the GSD of the material to the BU specification (assuming COC levels are acceptable) and an estimate of the tons dry weight of material available. Assuming that the available GSD and contaminant data point to separation as a possible management approach, the MRP following separation must be determined.

The definition of MRP is expressed in terms of tons dry weight of product for two reasons. First, volumes and wet weights may change with the relative gain or loss of water during separation or dewatering processes, but the dry weight of product is essentially constant. Second, project requirements for a product derived from separation would usually be expressed on a dry weight basis. This is especially true for products such as fine aggregates or manufactured soil products. Following separation, the product intended for BU and the residual material will have different grain size distributions compared to the bulk material distribution prior to separation. Figure 4 illustrates the typical case in which the desired product is specified as having a coarser grain size distribution than the initial material prior to separation. The specifications for an acceptable product will usually include a range of grain sizes, and this is illustrated by the band of distributions shown in the figure.

The recommended method for calculating MRP is as follows:

$$\mathrm{MRP} = \sum_{i=0}^{i=n} P_{si}\, W_{si} \tag{1}$$

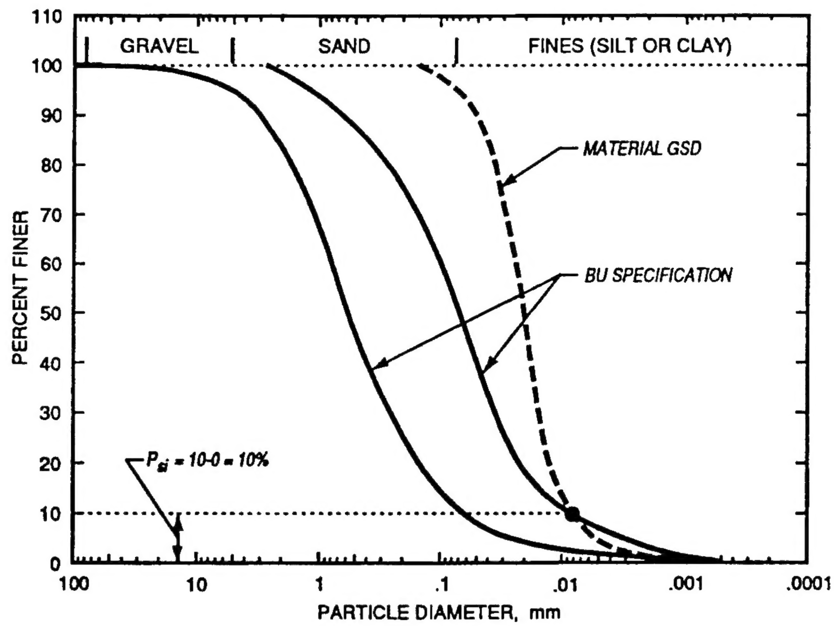
where

MRP = material recovery potential, tons

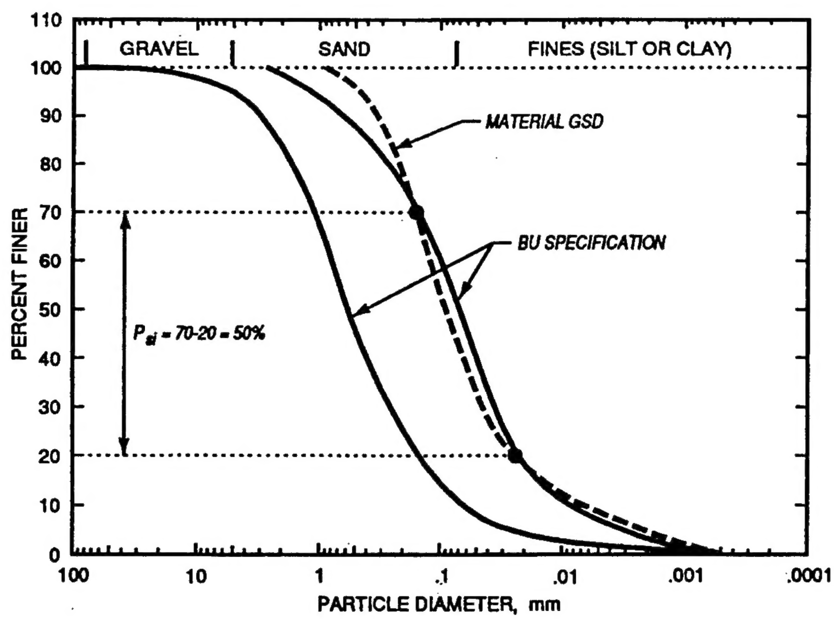
P_{si} = percentage by weight of sample grain size meeting the BU material specification for sample i (as a decimal)

W_{si} = dry weight of material represented by sample i, tons

n = number of samples considered



a. $P_{si} = 10$ percent



b. $P_{si}/4 = 50$ percent

Figure 4. Recoverable percentage P_{si} for material having finer GSD than BU specification

The percentage of material in a given sample meeting the specifications P_{si} can be estimated based on the overlap of the GSD curve for that sample and of the BU specification range. Figure 4a illustrates a relatively large proportion of the material volume potentially meeting the specifications, while Figure 4b illustrates a relatively small proportion meeting specifications. The proportion meeting specifications (in percent) will determine the MRP. In cases where the BU specification is given as a single D_{50} grain size, the value of P_{si} can be determined as shown in Figures 5 and 6. Analytically, this can be expressed as:

For $D_{50} < D_{50spec}$: $$P_{si} = (100 - \% \text{ passing } D_{50spec}) \times 2 \tag{2}$$

For $D_{50} > D_{50spec}$: $$P_{si} = \% \text{ passing } D_{50spec} \times 2 \tag{3}$$

The tons dry weight represented by a sample W_{si} can be estimated as follows:

$$W_{si} = (0.0135) V_i (\gamma_i) \tag{4}$$

where

W_{si} = dry weight of solids represented by sample *i*, (tons)

V_i = volume represented by sample *i*, cubic yards (determined by survey data)

γ_i = unit weight of the dry material for sample *i*, lb/cu ft (determined based on water content or dry density measurement)

0.0135 = conversion factor

The calculation method shown here can be applied in the same way for an initial evaluation using existing GSD data or following collection of additional samples. This relationship for calculating MRP can be applied to individual samples representing an incremental volume of the total or an average of several samples representing either a composited volume or the total volume of interest. This will be determined, as previously mentioned, based on the variability of the site and the expected compositing of the material for processing. Some data estimating approaches described in Olin-Estes (2000) may also be helpful in segmenting the volume between data points.

CONSIDERATION OF RESIDUAL VOLUME CHANGES: Although a proportion of the total mass dry weight of the material may be recoverable, the resulting increase in volume (bulking) of the residual materials should be evaluated in determining the advisability of separation. For example, if 50 percent by weight of the material in an existing CDF is removed, the resulting capacity recovered within the CDF will be less if hydraulic methods are used in the separation process. The residual fine fraction will increase in volume (bulking), at least in the short term. The same would hold true if hydraulic separation methods were applied as a follow-on to mechanical dredging/ rehandling operations. Residual materials can be mechanically dewatered successfully, eliminating the problems resulting from bulking, but mechanical dewatering is typically one of the more expensive unit processes in a physical separation treatment train.

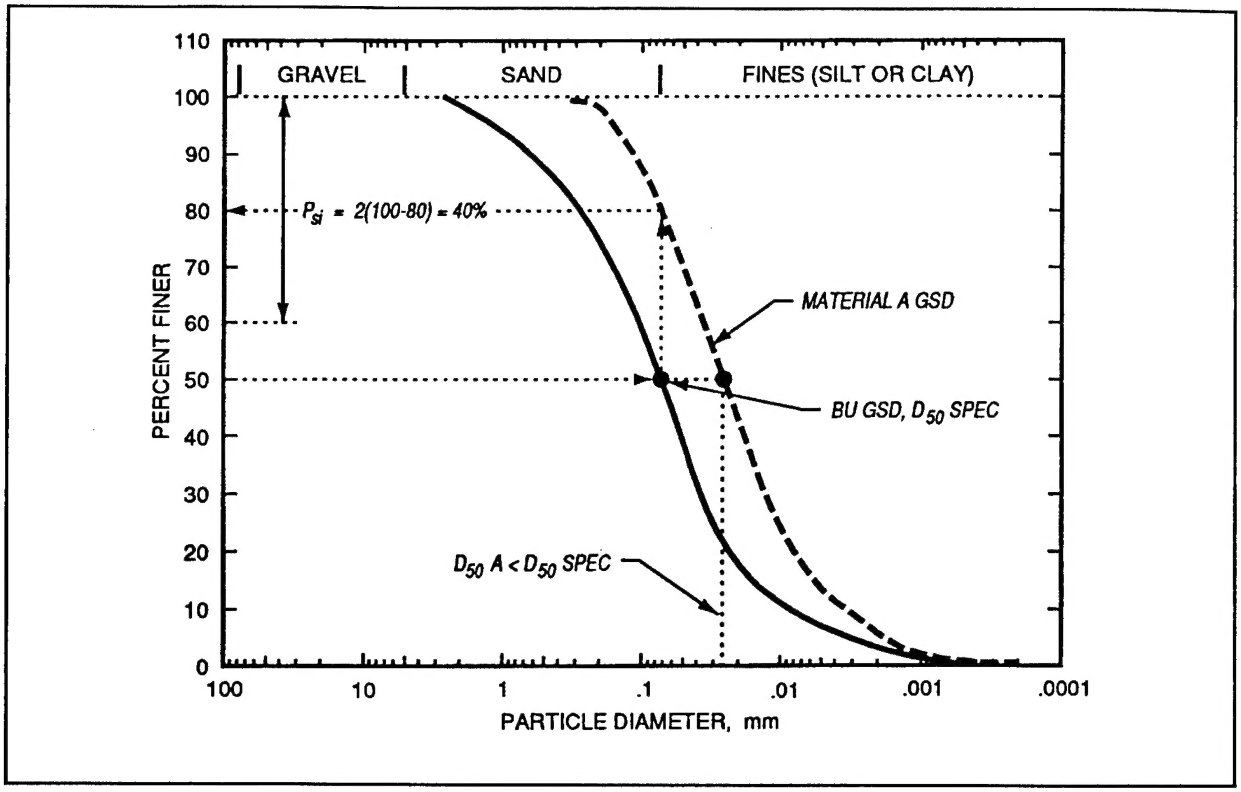


Figure 5. P_{si} for material with $D_{50} < D_{50}$ BU specification

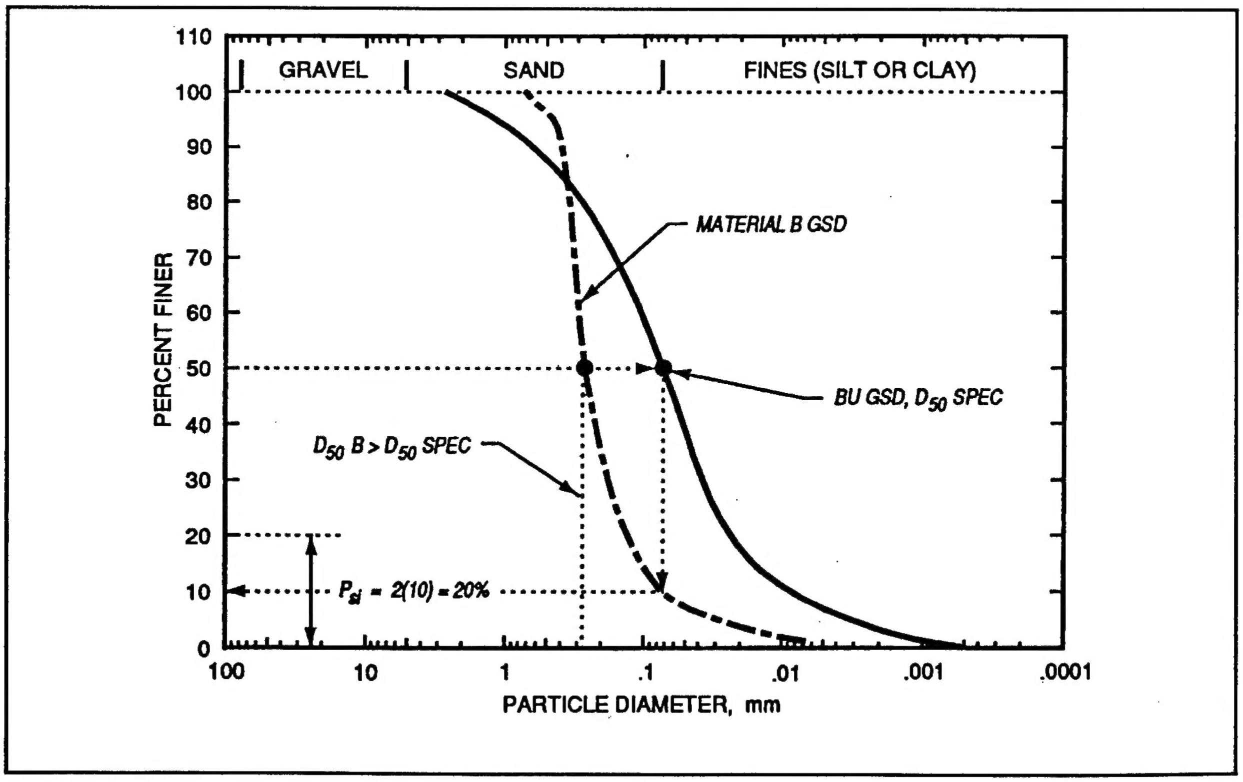


Figure 6. P_{si} for material with $D_{50} > D_{50}$ BU specification

Methods for estimating the volumes occupied by hydraulically dredged material as a function of time and operational factors are given in Engineer Manual (EM) 1110-2-5027 (Headquarters, U.S. Army Corps of Engineers, 1987). These methods rely on column settling tests to evaluate volume changes during hydraulic placement of fine-grained material, and may be applied directly in evaluating potential changes in volumes of fine-grained fractions resulting from hydraulic separation methods. The calculations would require laboratory test data as described in EM 1110-2-5027, particularly as the overflow from a separation process will typically present a more dilute slurry than a hydraulic dredge discharge, for which this guidance was designed.

COMPLETION OF SEPARATION FEASIBILITY EVALUATION: Once a reliable estimate of MRP has been developed, the information can be used in completing the evaluation of separation feasibility. If recovery potential matches the requirements for the BU applications under consideration, fractionation testing should be conducted to determine if separated fractions meet the requirements related to residual COC. If these results are favorable, appropriate operational methods or equipment for separation can be selected, and a cost analysis can be performed. Procedures for these aspects of the evaluation are described in Olin et al. (1999).

CONCLUSIONS: Development of a reuse plan for a CDF or dredging project will require a multistep approach incorporating existing data, identification of local BU opportunities and requirements, and practical and/or statistical sampling approaches. Physical separation is only one of several approaches that can be taken to produce material suitable for various beneficial uses, and should be evaluated together with other alternatives to determine the most suitable approach for a given site.

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> Olin-Estes, T. J., and Palermo, M. R. (2000). "Determining recovery potential of dredged material for beneficial use – Soil separation concepts," *DOER Technical Notes Collection* (ERDC TN-DOER-C13), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

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